Vznik a vývoj Země a vnějších zemských obalů

Velký třesk 15Ga – elementární částice, lehké prvky (H a He) vytváří hvězdy a galaxie první generace – bílé trpaslíky. V neutronových hvězdách, černých dírách se tvoří další lehké prvky, výbuchy supernov dochází k tvorbě těžších prvků, vznikají hvězdy druhé generace s planetami – chemická evoluce → geologická → biologická evoluce

Dopplerův rudý posuv

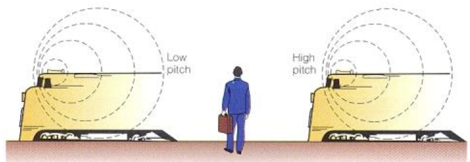


FIGURE 7.2 The Doppler effect applied to sound waves. The sound waves of an approaching whistle are slightly compressed so that the individual hears a shorter-wavelength, higher-pitched sound. As the whistle passes and recedes from the individual, the sound waves are slightly spread out, and a longer-wavelength, lower-pitched sound is heard.

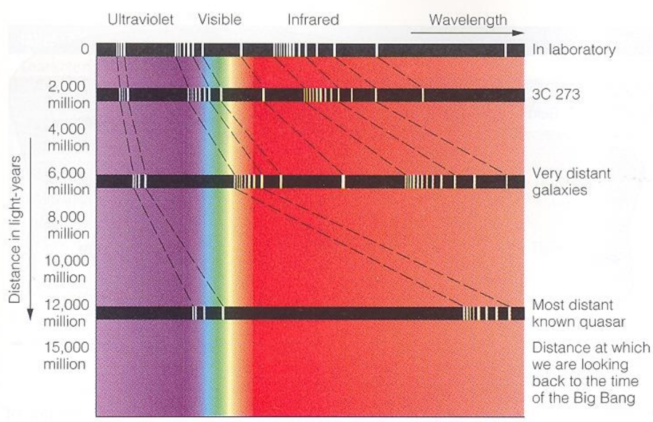


FIGURE 7.1 Spectra showing the redshift of the galaxies. Just as the Doppler effect makes a rapidly receding train whistle drop in pitch, the expansion of the universe stretches light waves from receding objects toward the longer wavelengths of the spectrum. This light is said to be *redshifted,* and the amount of the redshift is proportional to the object's distance from us. In this diagram the spectral lines of hydrogen are stretched in proportion to their original wavelengths. All lines in the spectrum of any object, however, exhibit the same ratio of wavelength increase to the original wavelength.

Vznik sluneční soustavy

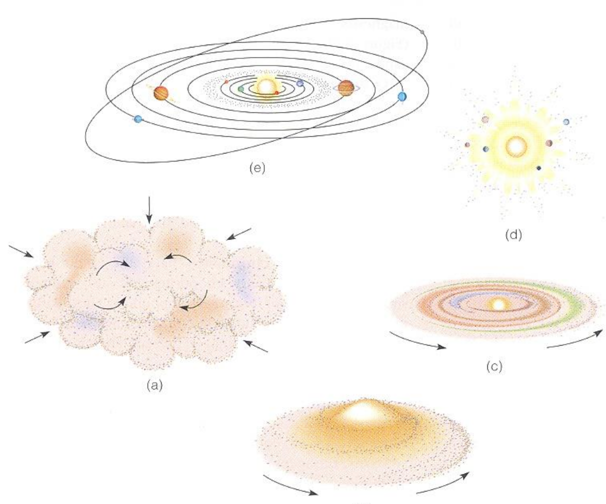
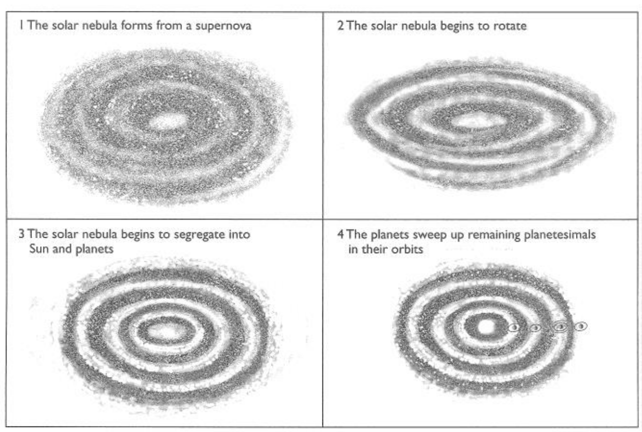


FIGURE 7.6 The currently accepted theory for the origin of our solar system involves (a) a huge nebula condensing under its own gravitational attraction, then (b) contracting, rotating, and (c) flattening into a disk, with the Sun forming in the center and eddies gathering up material to form planets. As the Sun contracted and began to visibly shine, (d) intense solar radiation blew away unaccreted gas and dust until finally, (e) the Sun began burning hydrogen and the planets completed their formation.

Vznik sluneční soustavy z mlhoviny



Vznik Země: akrece

EARTH DIFFERENTIATION

- **How did the layering occur?**
  - Two hypotheses
    - Homogenous accretion (cold)
      - uniform density at beginning
      - warming melts iron and nickel etc.
      - warming from?
        - bombardment by particles
        - radioactive decay
        - compression

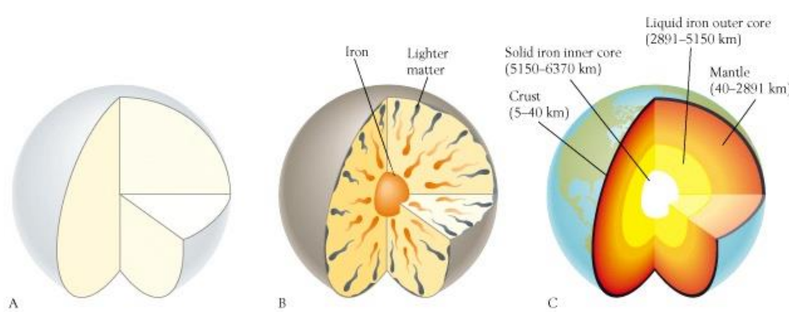
Homogenní akrece

Homogeneous Accretion Model

•Material with carbonaceous chondrite composition is heated, melted, and fractionated.
•Fe-Ni settles to core of body (gravity)
•Volatiles are degassed
•Si is concentrated in a "crust"
•Leaving mantle-like achondrite region.

Origin of Earth (cont.)

Homogeneous molten Earth → Segregation of materials by density → Final differentiation of core/mantle/crust



Heterogenní akrece

Heterogeneous Accretion Model

•Fe-Ni and other refractory elements condense first.

•If accretion times are rapid compared to condensation times, an Fe-Ni core accretes first, followed by silicate mantle

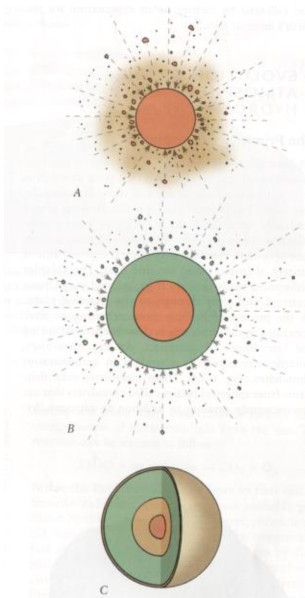
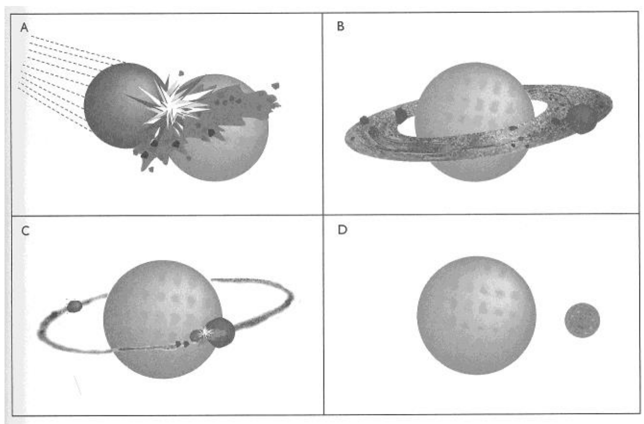


FIGURE 6–8 Origin of the Earth's core according to the hot heterogeneous model of accretion. (A) Primarily iron and nickel condense, collect, and form a core. (B) Silicates envelop the earlier formed core and form a mantle. (C) The mantle differentiates and provides the materials for the crust.

Vznik Měsíce
Origin of the Moon

- **<u>Moon</u>** originated when a large (Mars-size) body collided with Earth ("*glancing blow*")
  - Core of impacting body was absorbed into Earth's core
  - Remaining mantle of impacting body and was then captured in Earth's gravitational field
- Collision caused Earth's *rotation to increase*
- Moon has *no water*; a *metallic core* and *feldspar-rich outer layer*; relative abundance of iron and magnesium differ from that in Earth's mantle

Vznik měsíce



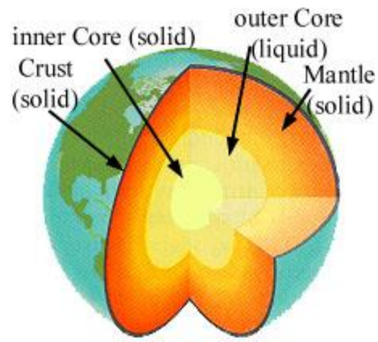
Stáří Země

EARTH DIFFERENTIATION

- **Crust**
  - Oldest rocks on Earth
- **How old is Earth ??**
  - Indirect evidence
    - moon rocks - oldest 4.6 by
    - meteorites - oldest 4.6 by

Prvotní zemská kůra

Horninový cyklus



After the initial segregation into a central iron (+nickel) core and an outer silicate shell, further differentiation occurred into an inner (solid) and outer (liquid) core (a pressure effect: solid iron is more densely packed than liquid iron), the mantel (Fe+Mg silicates) and the crust (K+Na silicates). The magma ocean would have cooled to form **a layer of basaltic crust** (such as is present beneath the oceans today). Continental crust would have formed form later. It is probable that the Earth's initial crust was **remelted several times** due to impacts with large asteroids.

Vznik atmosféry

Earth's early atmosphere

- Earth **did not** inherit its atmosphere from the initial asteroids that coalesced to form it
- Earliest atmosphere was generated by **emission of internal gases** (*similar to those emitted today from volcanoes*):
  - Water vapor, hydrogen, hydrogen chloride, carbon monoxide, carbon dioxide, nitrogen
- Note **absence of oxygen**, which was rare prior to the advent of *photosynthetic organisms*!

Vznik hydrosféry

Earth's early oceans

- **Ocean water** originated partly from emitted **water vapor** and partly from **icy comets** as they melted upon entry into Earth's atmosphere
  - 15 million small comets (~12 meters in diameter) enter Earth's atmosphere every year!
- **Salts** were added to the oceans from rivers carrying by-products of chemically weathered rocks
  - Salinity **stabilized** very early in Archean time because salt is removed from the oceans by precipitation of salt minerals

Odplynění pláště

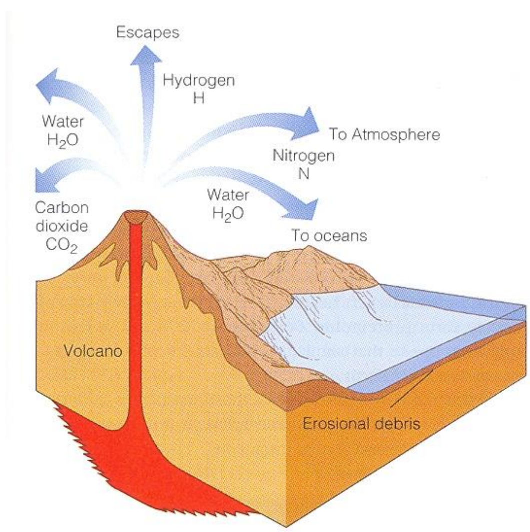


FIGURE 8.12 Outgassing released gases to form an early atmosphere composed of the gases shown. Chemical reactions in the atmosphere also probably yielded methane (CH_4) and ammonia (NH_3).

Zdroj O_2: Fotochemická disociace a fotosyntéza

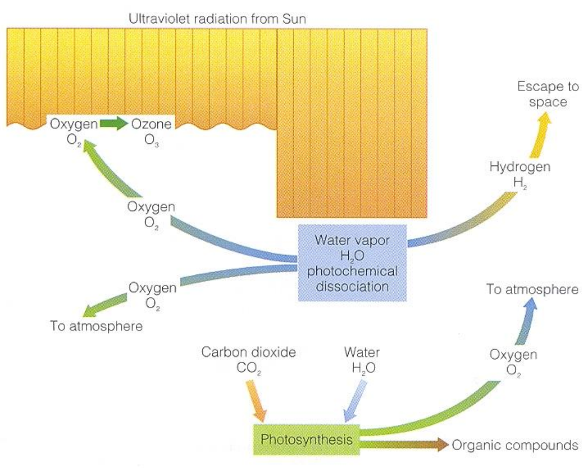


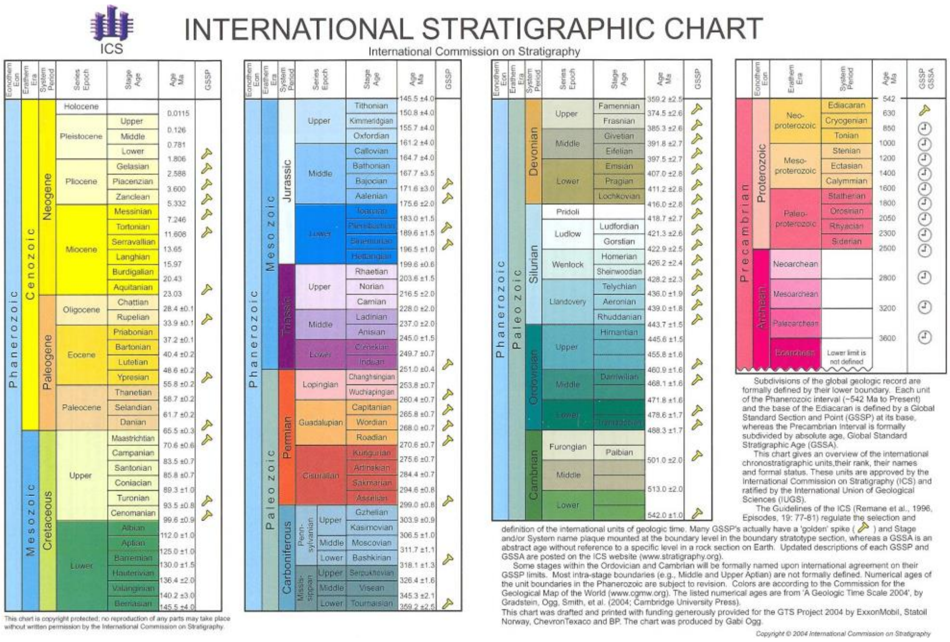
FIGURE 8.13 Photochemical dissociation and photosynthesis added free oxygen to the atmosphere. Once free oxygen was present, an ozone layer formed in the upper atmosphere and blocked most incoming ultraviolet radiation.

Chronologie prekambria

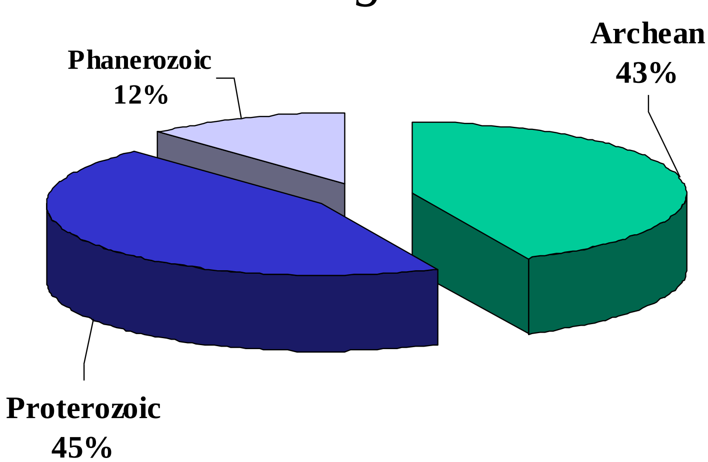
Prekambrium

The Precambrian is an informal name given to the age of the first three eons of Earth history.

1. **Hadaikum** 4.6 - 3.8 bya (or 4.6 - 3.96 bya)
   No rock record. This is the time of the origin of the Earth. Earth was mostly hot molten rock at that time.
2. **Archaikum** 3.8-2.5 bya
3. **Proterozoikum** 2.5-0.544 bya



Geologic time



Hadaikum

Hadaikum

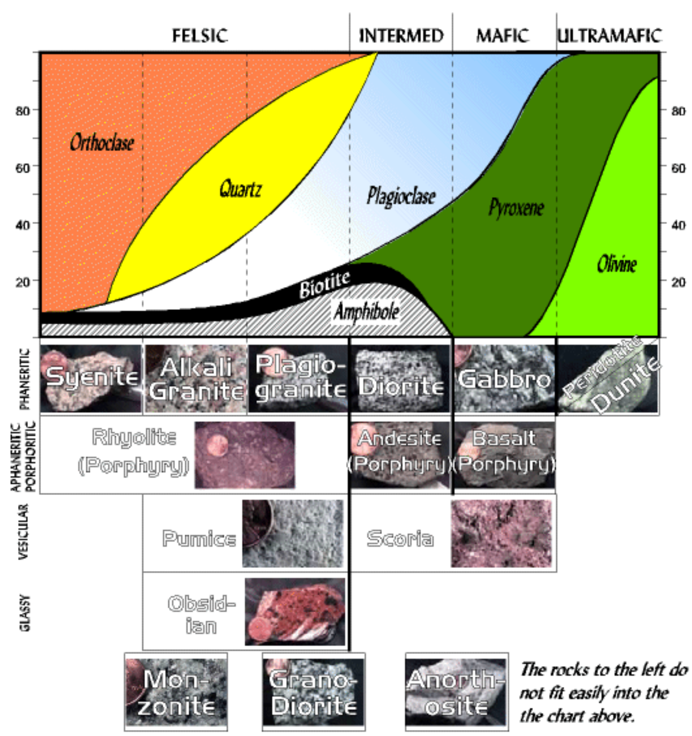
- A time of major changes and Earth formation.
  No rock record.
- **Differentiation of the Earth to form crust, mantle and core**
- **Origin of the atmosphere**
  Volcanic outgassing (or degassing)
  H_2O, H_2, HCl, CO, CO_2, N_2, Sulfur gases
  Little or no free oxygen (O_2); would lead to rapid oxidation of iron minerals
- **Condensation of water vapor formed the hydrosphere**
  ((3,8, ?4,4 Ga) rain; runoff leads to lakes, rivers, oceans
  originally freshwater (rain); may have been acidic from sulfurous gases
  slow accumulation of salts due to weathering
- Beginnning of formation of **oceanic and continental crust** of Earth.

Vývoj zemské kůry v hadaiku a archaiku

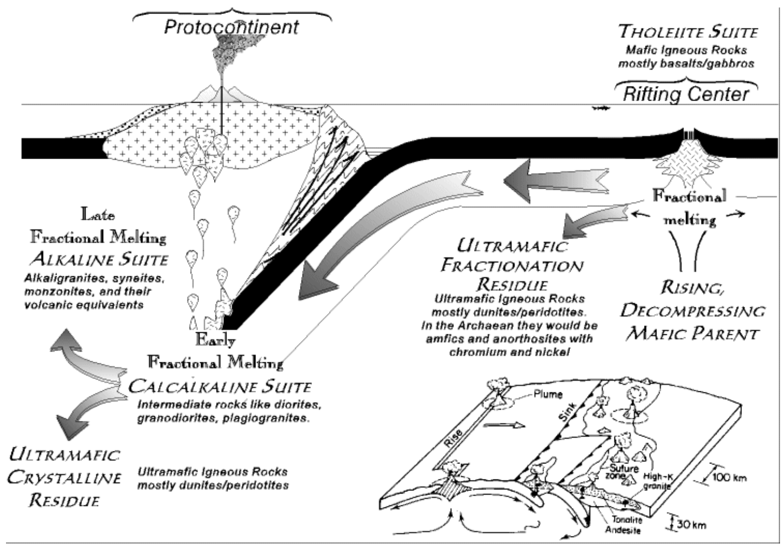
Archaean Crustal Evolution and the Formation of Continents

The earth began in a state similar to the moon with a crustal (lithospheric) surface composed dominantly of **mafic/ultramafic igneous rocks and anorthosites**. With the formation of the oceans the early earth would have been a relatively simple world compared with today - oceans from pole to pole, with occasional scattered hot spot volcanos. Quickly, however, **convection cells** established divergent and convergent plate boundaries which began the **fractionation processes** that would build the continents.

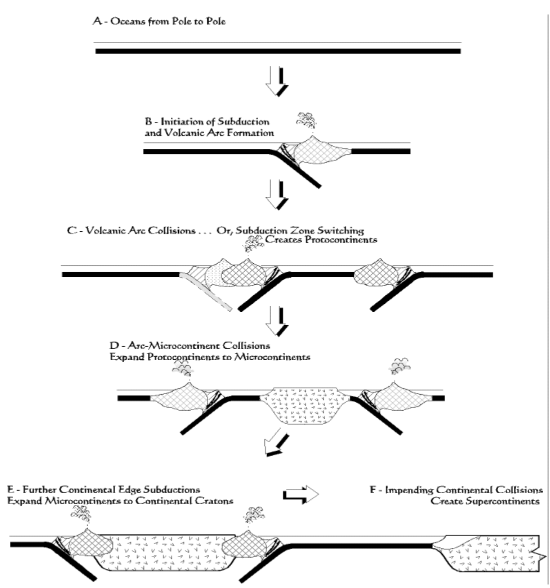
The sequence of cross sections below illustrate the kinds of processes by which initial volcanic arcs could increase in size to form protocontinents, then through cordilleran orogenies and collisions form protocontinets, which would grow to form **microcontinents**, which would eventually grow to form **supercontinents.** All of these processes constitute variations on the Wilson cycle. The combinations and permutations of relationships is virtually endless. Anything that could reasonably happen, probably happened.



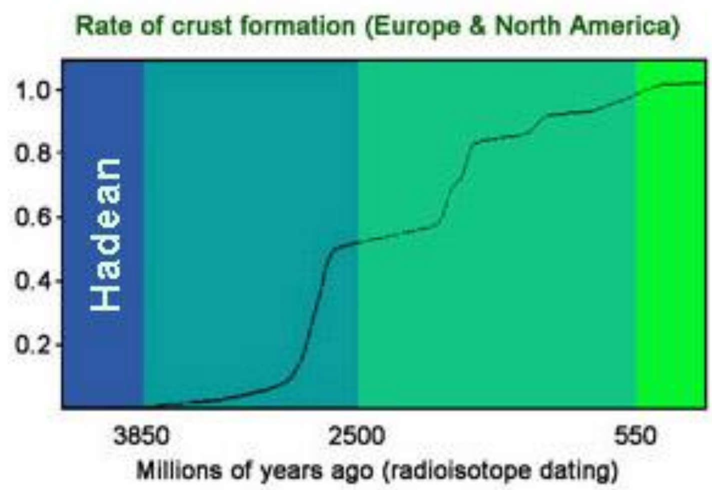
Protokontinenty



Wilsonův cyklus



Rychlost nárůstu zemské kůry



Nejstarší horniny

Nejstarší horniny na Zemi jsou:

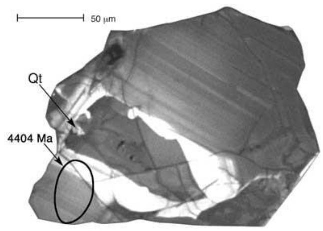
- **Acasta Gneisses** in northwestern Canada near Great Slave Lake (**4.03 Ga**)
- **Isua** supracrustal rocks (metasedimenty) in West Greenland (**3.7 to 3.8 Ga**),

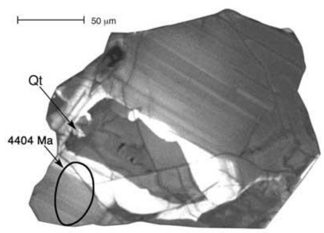
Nejstarší minerály na Zemi jsou:

- **Pilbara Craton**, **mineral grains (zircon) with U-Pb ages of 4.4 Ga** have recently been reported from **sedimentary rocks in west-central Australia**. Zircons dated at 4.3 billion years were reported from the same site a decade ago, but the new-found zircon grain is more than 100 million years older

By probing a tiny grain of zircon, a mineral commonly used to determine the geological age of rocks, scientists from the University of Wisconsin-Madison, Colgate University, Curtin University in Australia and the University of Edinburgh in Scotland have found evidence that 4.4 billion years ago, temperatures had cooled to the 100-degree Centigrade range, a discovery that suggests an early Earth far different from the one previously imagined

What the oxygen isotopes and rare earth analysis show us is a high oxygen isotope ratio that is not common in other such minerals from the first half of the Earth's history," Peck says. In other words, the chemistry of the mineral and the rock in which it developed could only have formed from material in a low-temperature environment at Earth's surface.





Cathodoluminescence image of the oldest known material from the Earth, a **single crystal of zircon from the Jack Hills** metaconglomerate, Western Australia. Photo: NSFThe

4.4-billion-year-old mineral sample suggests that early Earth was not a roiling ocean of magma, but instead was cool enough for water, continents, and conditions that could have supported life.

What the oxygen isotopes and rare earth analysis show us is a high oxygen isotope ratio that is not common in other such minerals from the first half of the Earth's history," Peck says. In other words, the chemistry of the mineral and the rock in which it developed could only have formed from material in a low-temperature environment at Earth's surface.

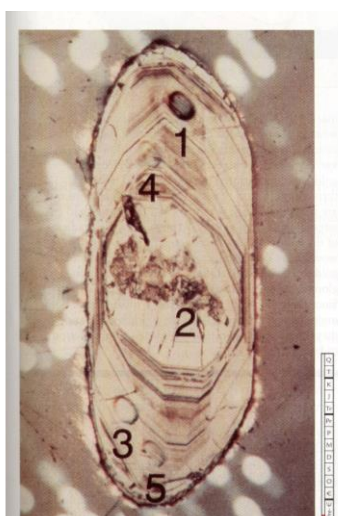


FIGURE 6–18 Photomicrograph of one of the 3.96-billion-year-old zircon grains extracted from the Acasta Gneiss, Slave province, Northwest Territories of Canada. The grain is 0.5 mm long. Its polished surface has been etched with acid to highlight crystal growth zones. Numbers refer to points selected for analysis. *(Courtesy of S. A. Bowring.)* Why are zircon crystals particularly valuable in determining isotopic ages?

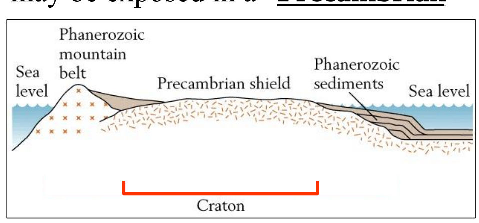
Výskyty prekambrických hornin

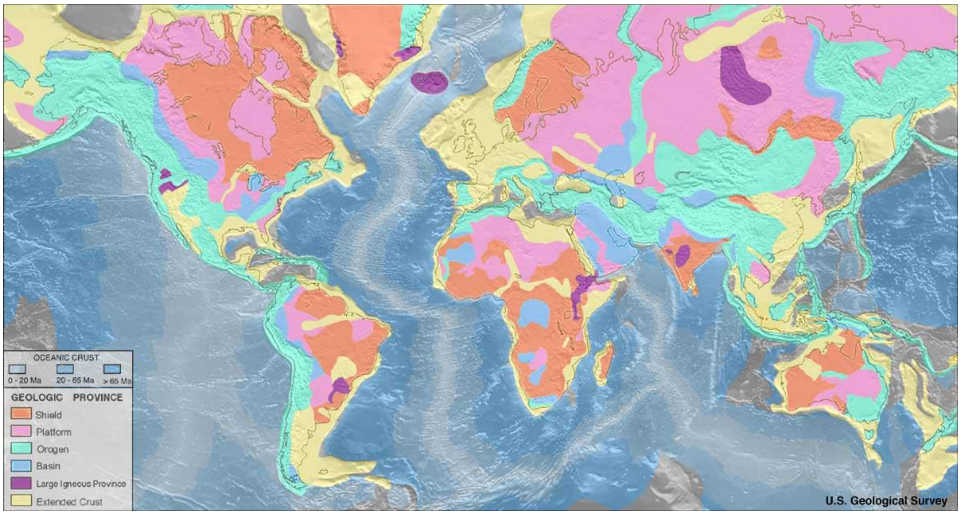
Precambrian rocks

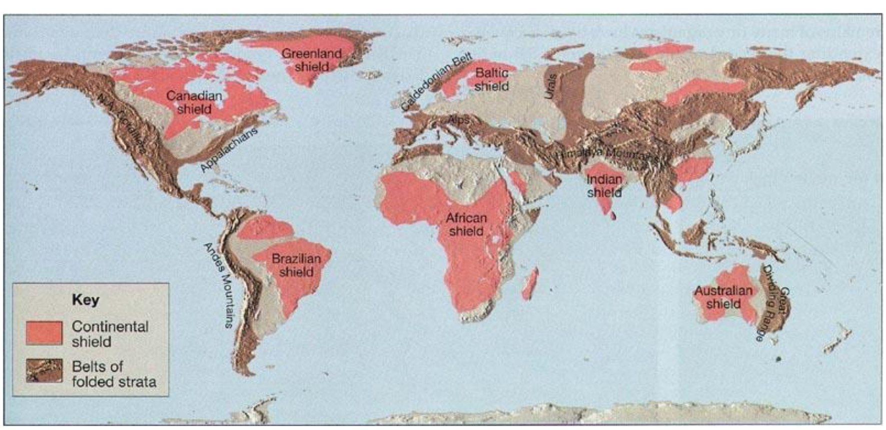
- Although Precambrian time accounts for 88% of Earth's history, **Precambrian rock exposures** make up only about *20% of Earth's land surface*
- Most Precambrian rocks have been destroyed in the course of plate tectonic cycles (and most remaining ones are buried beneath the veneer of Phanerozoic rocks)

Precambrian rocks

- **Cratons** are the large, stable, interior regions of continents that *have not undergone major deformation since Precambrian or early Phanerozoic time*
- Most Precambrian rocks are confined to cratons, where they may be exposed in a "**Precambrian shield**"




OCEANIC CRUST
0 - 20 Ma
20 - 65 Ma
> 65 Ma
GEOLOGIC PROVINCE
Shield
Platform
Orogen
Basin
Large Igneous Province
Extended Crust
U.S. Geological Survey


Greenland shield
Canadian shield
Baltic shield
Caledonian Belt
Urals
Alps
Appalachians
Himalaya Mountains
Indian shield
African shield
Brazilian shield
Andes Mountains
Australian shield
Great Dividing Range
Key
Continental shield
Belts of folded strata

Prekambrium

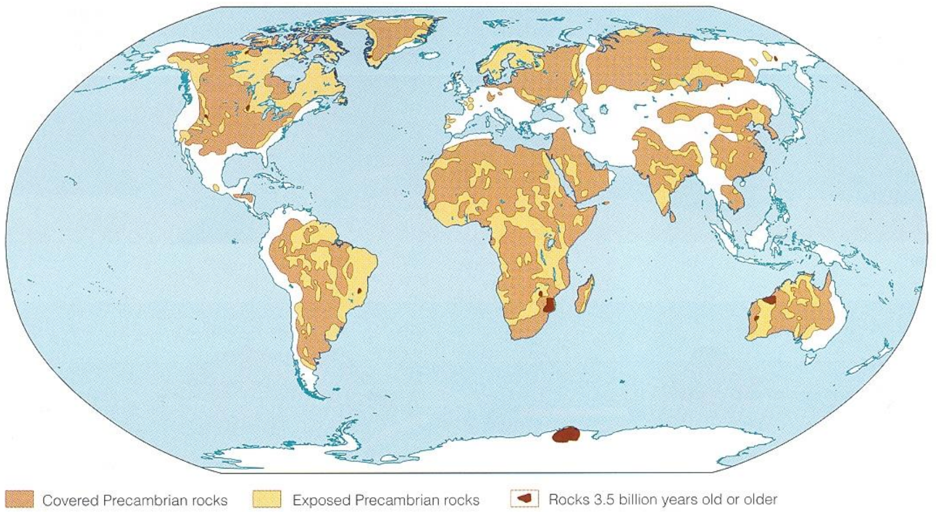


FIGURE 8.4 Precambrian cratons of the world. The areas of exposed Precambrian rocks are the shields, while buried Precambrian rocks are the platforms. Shields and platforms collectively make up the cratons.

Archean Rocks

1. **Granulites** - high grade metamorphic rocks (gneiss and anorthosite)
2. **Greenstone belts** - volcanic and sedimentary rocks commonly metamorphosed
   chlorite produces green color
   Sedimentary rocks altered to metasedimentary rocks
   metagraywackes, slates, schists, metaconglomerates, diamictites
   some relict sedimentary structures
3. **Sedimentary rocks** altered to metasedimentary rocks
   metagraywackes, slates, schists, metaconglomerates, diamictites
   some relict sedimentary structures
4. **Banded Iron Formations red chert** (jasper) and unoxidized iron-rich sedimentary rocks. First appear 3.8 Ga; much more common in Proterozoic. Rare after 1.9 Ga, last appear c. 720 Ma. Major iron ore.

•**Granitoid-Greenstone Complex**:

•**<u>THE</u> typical Archean lithological suite.**

•**Pods of metamorphosed granitic rock (now gneisses) separated by greenstone belts: bands of sequences of weakly metamorphosed komatiites -> basalts -> felsic volcanics -> marine sediments (turbidites, cherts, banded iron formations, etc.).**

•**Oldest 4.03 Ga, disappear around 2.5 Ga.**

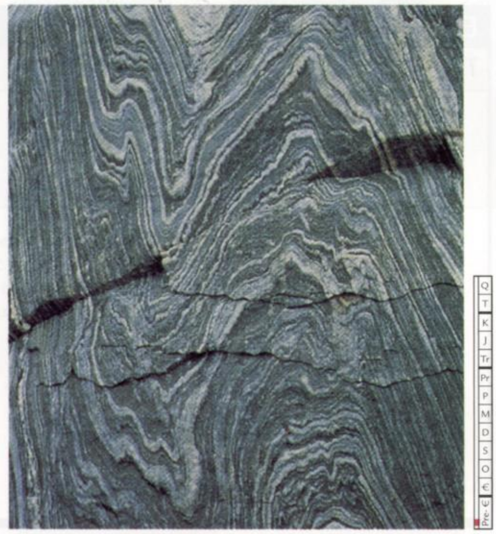
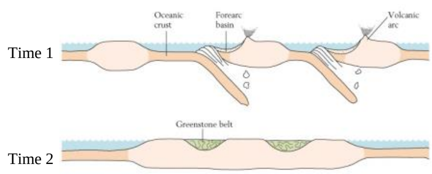


FIGURE 6–19 Archean tonalite gneiss, about 3.8 billion years old, exposed near Lile Narssuaq, Greenland.
Would tonalite be considered a felsic or mafic rock?

Archean rocks (cont.)

- **Greenstone belts**
  - Make up *large portions* of Archean terranes
  - Age of most greenstone belts is ~2.5–3.0 billion years
  - **Elongate belts** of *weakly metamorphosed* rock separating larger masses of *felsic protocontinents*
  - Include **metamorphosed mixtures** *of mafic and felsic volcanics, volcanic sediments, turbidites*
    - Assemblage of precursor rocks is characteristic of forearc basins and subduction zones
  - Probably formed along *subduction zones* where *protocontinents were sutured together*

Formation of greenstone belts



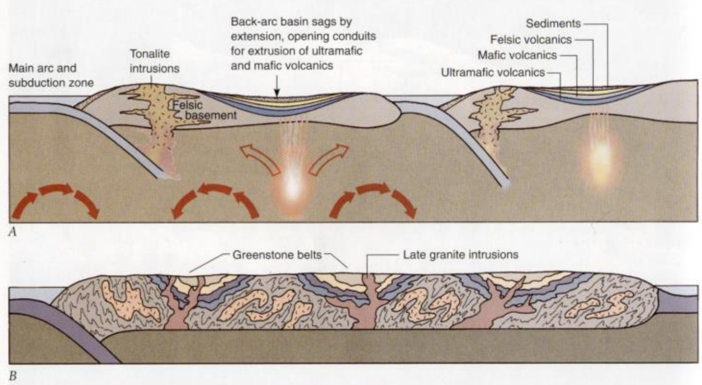


FIGURE 6–24 Plate tectonics model for the development of greenstone belts and growth of continental crust. (A) Plates are in motion, driven by convection cells in the upper mantle. Subduction provides for the emplacement of wedges of oceanic crust and for mixing and melting to provide tonalite intrusions. Behind the main arc, the back arc sags by extension, and the greenstone volcanic sequence is extruded. (B) Compression has occurred to create the greenstone belts with their synclinal form and to aggregate small continental patches into a larger continental mass. Later, granites are intruded in and around greenstone belts. *(Simplified from a model proposed by B. F. Windley, 1984. The Evolving Continents, 2nd ed. New York: John Wiley & Sons.)*

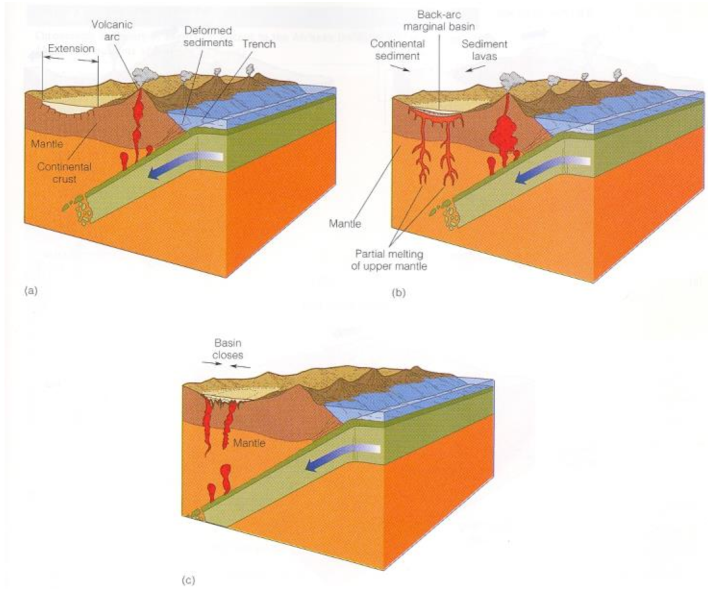


FIGURE 8.8 Formation of a greenstone belt in a back-arc marginal basin. (a) Rifting on the continent side of a volcanic island arc forms a back-arc marginal basin. Partial melting of subducted oceanic crust supplies andesitic and dioritic magmas to the island arc. (b) Basaltic lavas and sediments derived from the continent and island arc fill the back-arc marginal basin. (c) Closure of the back-arc marginal basin causes compression and deformation. The greenstone belt is deformed into a synclinal structure and is intruded by granitic magmas.

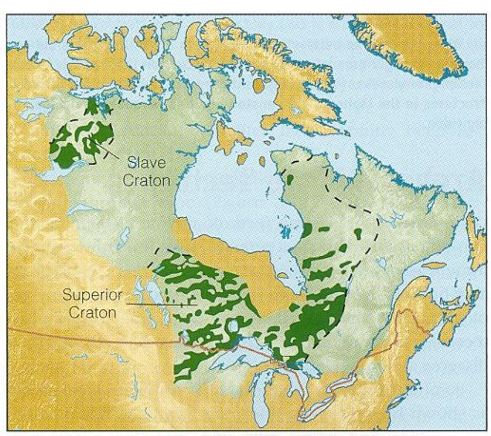
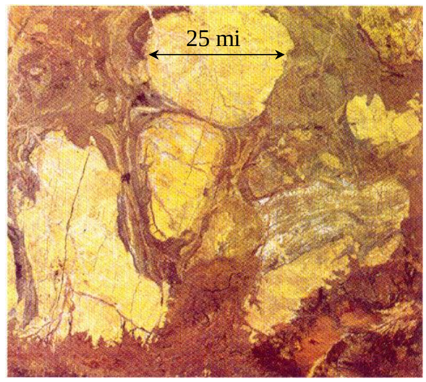


FIGURE 8.6 Archean greenstone belts (shown in dark green) of the Canadian Shield are mostly in the Superior and Slave cratons.

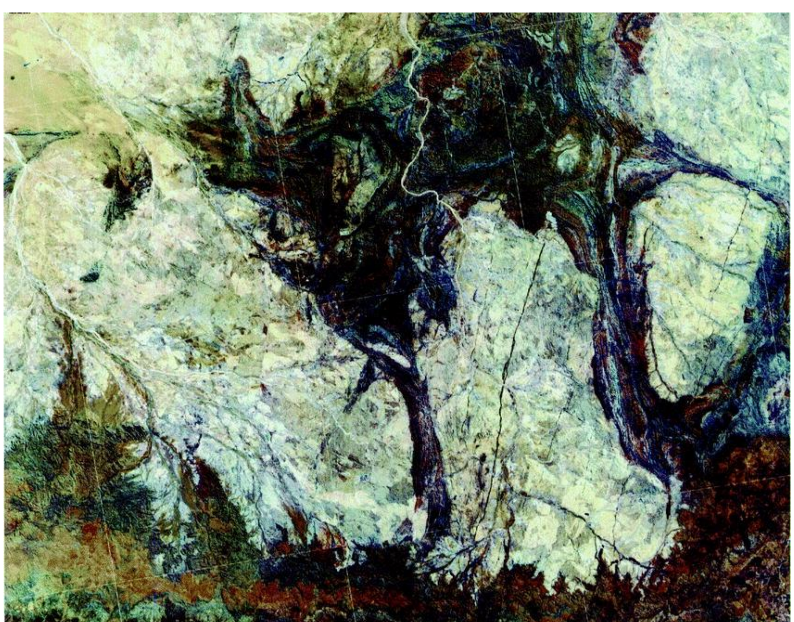
Greenstone belts consist primarily of volcanic rocks, typically basalts that have been altered by low grade metamorphism which produces chlorite - a greenish mineral. Some belts include ultramafic lava flows which require near surface temperatures of 1600°C. This means that the early mantle was nearly 300°C hotter than today. This suggests that the earth has cooled, probably as a result of a loss of radiogenic heat.
Two models have been proposed for the evolution of greenstone belts. 1) Back-arc spreading in marginal basins and 2) intracon-tinental rifts

Greenstone belts

Satellite view of Archean greenstone belts and felsic protocontinents in western Australia



Pilbara craton, NW Australia



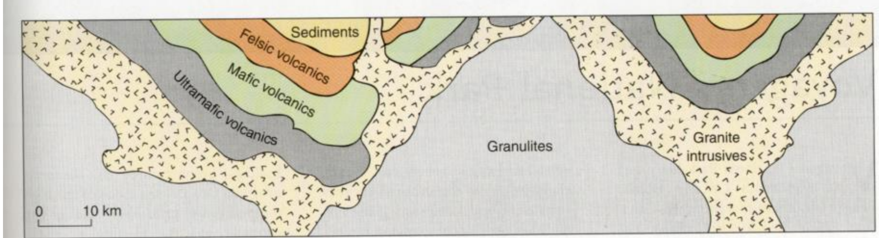


FIGURE 6–22 Generalized cross-section through two greenstone belts. Note their synclinal form and the sequence of rock types from ultrabasic near the bottom to felsic near the top. A late event in the history of the belt is the intrusion of granites. Ultramafic basal layers are particularly characteristic of greenstone belts in Australia and South Africa but do not occur in the Archean of Canada.

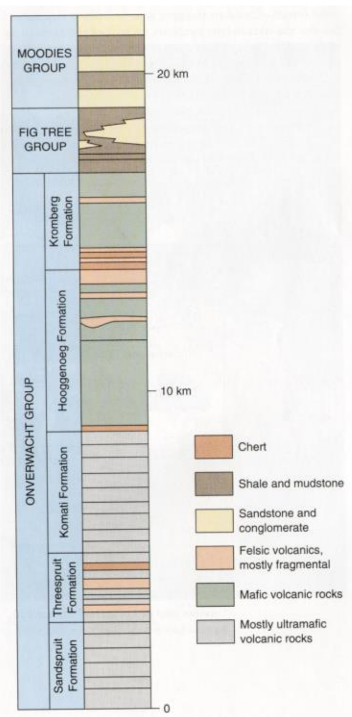
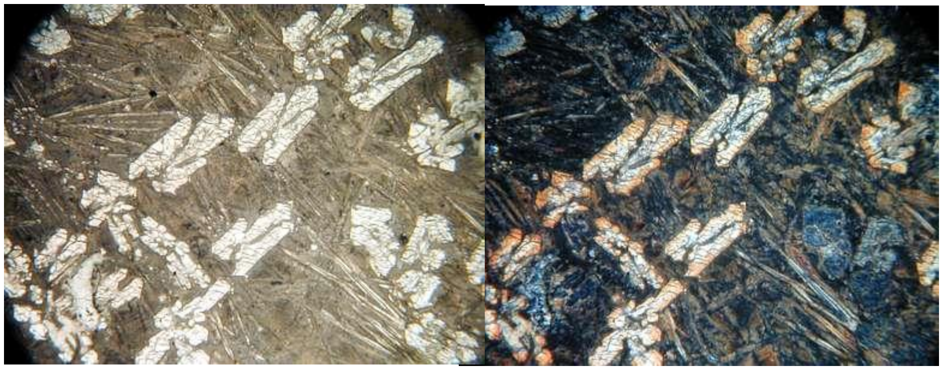


FIGURE 6–23 Stratigraphic sequence in a greenstone belt in Barberton Mountain Land, South Africa. *(After D. R. Lowe, 1980, Ann. Rev. Earth Planet. Sci. 8:145–167.)*

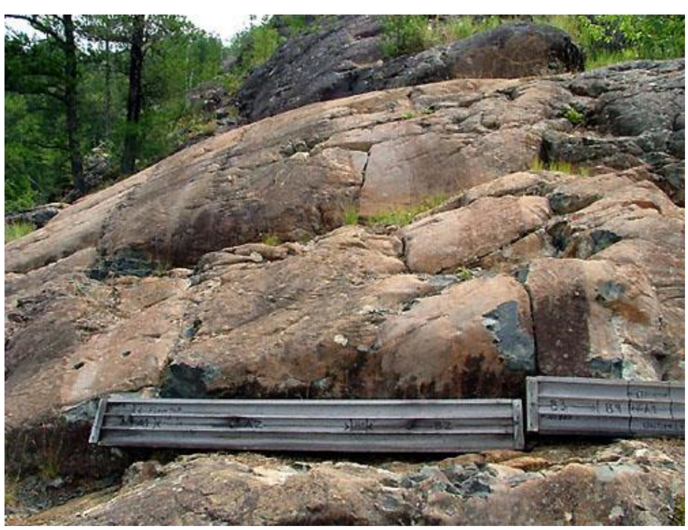
•**Komatiite**: Ultramafic volcanics, very common in Archean, very rare afterwards. Require temperatures of greater than 1600 şC (modern lavas max out at 1350 şC). Hint at the extreme activity of Archean mantle.

Clinopyroxen crystals andspinifex texture in komatiite



Komatiites are **ultramafic** volcanic rocks, having very low *silica* contents (~40-45%) and very high MgO contents (~18%. These ancient lava flows erupted at a time when the *Earth's internal heat* was much greater than today, thus generating exceptionally hot, fluid lavas with calculated eruption temperatures in excess of 1,600 degrees C (2,900 degrees F). In comparison, typical basaltic lavas erupting today have eruption temperatures of about 1,100 degrees C.

- Komatiite lava flow on Pike Hill. The core boxes are left there and labeled with the different flow units. Flow to to left.
  (Images courtesy of Laurent Montesi.)



Nejstarší ofiolit

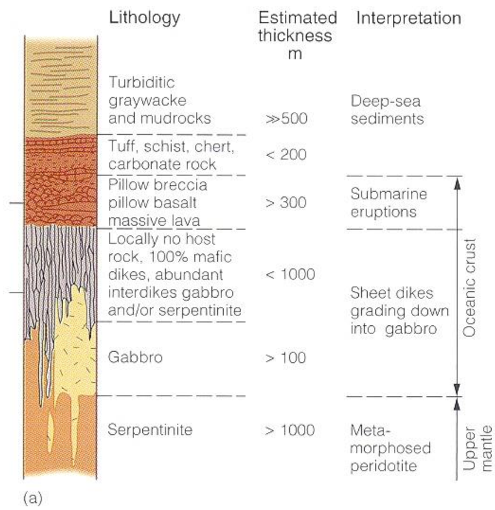
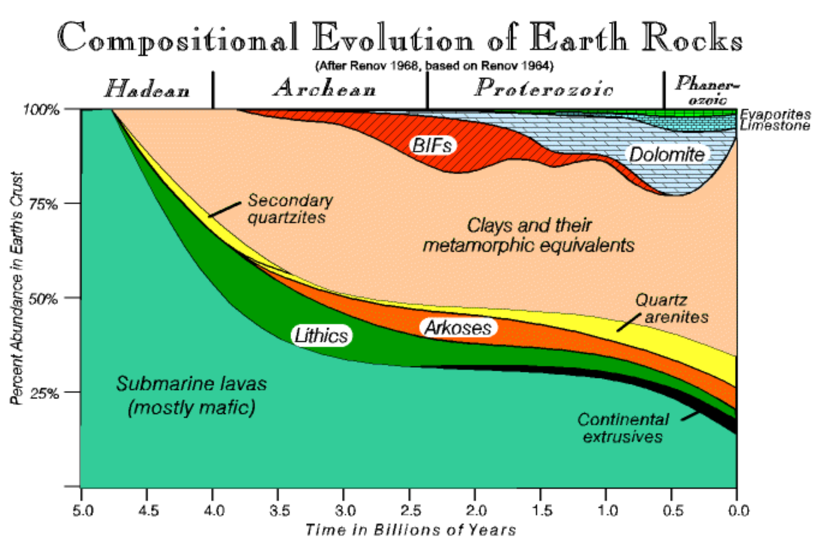


FIGURE 9.1 (a) Reconstruction of the highly deformed Jormua mafic–ultramafic complex of Finland. This 1.96-billion-year-old sequence of rocks is the oldest known complete ophiolite. (b) A metamorphosed basaltic pillow lava. The code plate is 12 cm long. (c) Metamorphosed gabbro between mafic dikes. The hammer shaft is 65 cm long.

- **<u>Archean sedimentary rocks</u>** are mostly of *deep-water origin*
  - Sandstones, cherts, shales, banded-iron formations
  - Very few, if any, limestones or evaporites
  - No well developed continental shelves for accumulation of shallow-water deposits



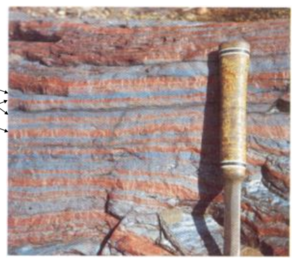
Archean rocks (cont.)

- **<u>Banded iron formations</u>**
  - Alternating bands of **<u>iron-rich</u>** layers and **<u>chert</u>** layers
  - Thought to have **<u>precipitated from hot marine water</u>** associated with igneous activity
  - Iron is **<u>weakly oxidized</u>** (looks like iron), suggesting little or no exposure to oxygen
    - Very few banded iron formations younger than 1.9 billion years old (when atmospheric O_2 increased)
    - Most iron deposits younger than 1.9 billion are highly oxidized (red beds)
  - Principal source of world's **<u>iron ore</u>**

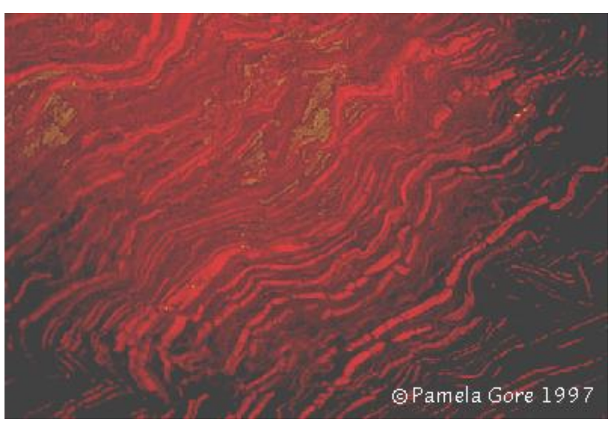
Banded iron formations

Iron layers

Chert layers (red)



Banded Iron Formation,
Alternating bands of red jasper and black hematite, about 2250 million years old (2.55 billion years old) Jasper Knob, Ishpeming, Michigan



Banding of BIF: record of episodic growth of microbes
- precipitation of Fe oxides followed by depletion of O2
- cycle repeats many times

Depoziční model vzniku BIF

FIGURE 9.15 Depositional model for the origin of banded iron formations.

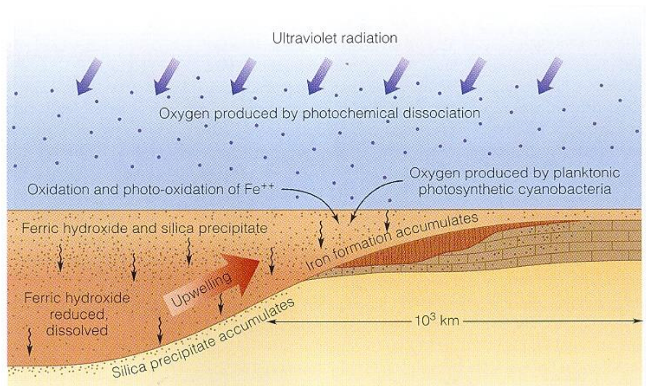
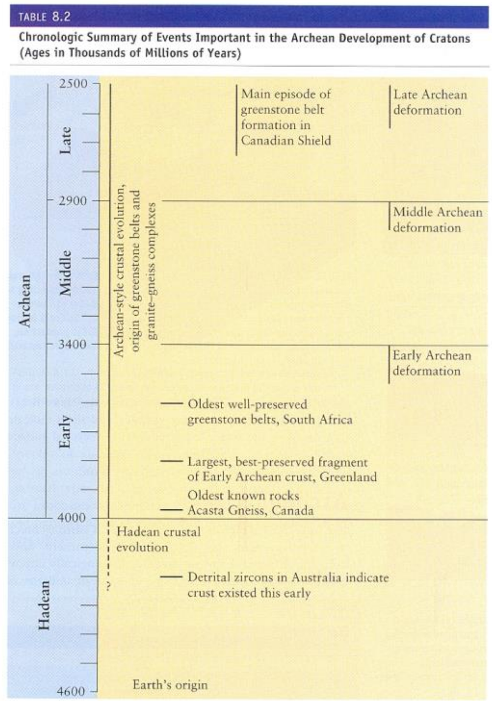


TABLE 6–3 Summary of the Characteristics of the Earth's Early Oceanic and Continental Crust

	Oceanic Crust	Continental Crust
First appearance	About 4.5 billion years ago	About 4.0 billion years ago
Where formed	Ocean ridges (spreading centers)	Subduction zones
Composition	Komatiite–basalt	Tonalite–granodiorite
Lateral extent	Widespread	Local
How generated	Partial melting of ultramafic rocks in upper mantle	Partial melting of wet mafic rocks in descending slabs

Source: Condie, K. C. 1989. Origin of the Earth's crust. *Paleogeography, Paleoclimatology, Paleoecology* 75:57–81, with permission.

Chronologický souhrn archaického vývoje kratonů



Vznik a raný vývoj života

Prokaryotní a eukaryotní buňka

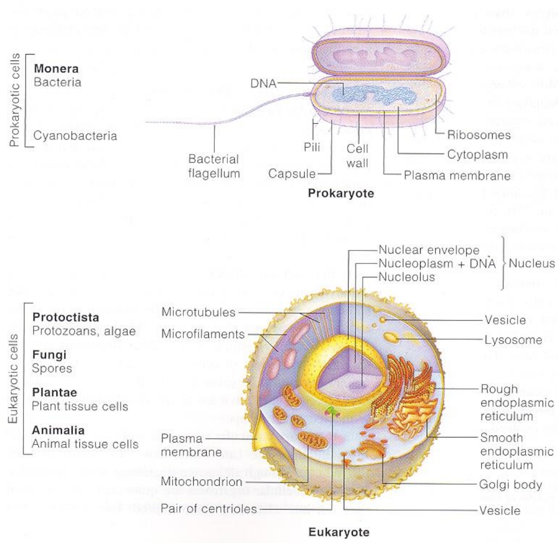


FIGURE 9.17 Prokaryotic and eukaryotic cells. Note that eukaryotic cells have a cell nucleus containing the genetic material and several organelles such as mitochondria and plastids, as well as chloroplasts in plant cells.

Translační systém

- Základní podmínkou života je existence tzv. **translačního systému**, který umožňuje reprodukci - přenos genetických informací a tvorbu bílkovin podle nich. Translační systém vznikal syntézou jednoduchých anorganických a organických látek až k složitým organickým sloučeninám v několika krocích:
- 1) syntéza HCN (kyanovodíku) a HCOH (formaldehydu);
- 2) syntéza aminokyselin a organických bází;
- 3) syntéza ribonukleotidů a kondenzačních činidel;
- 4) kondenzace ribonukleotidů a RNA pomocí kondenzačních činidel a možný vznik aminokyselin z proteinoidů;
- 5) vznik autokatalytické ribonukleové kyseliny (RNA), která byla schopna replikace bez přítomnosti enzymů (je známa u některých virů);
- 6) vznik ribonukleového translačního systému, mRNA, tRNA;
- 7) vznik a rozvoj translačního systému deoxyribonukleové kyseliny (DNA), která je stabilnější při přenosu informací než RNA.

Buněčná membrána

- Povrchová chemie částic některých minerálů (např. pyritu, FeS_2)
  - **autokatalytické reakce**
  - **autotrofní růst** organických látek.

Pravděpodobné místo činu:

hluboké moře, mimo dosah O2, chemosyntetické bakterie (P, Ni, Zn), středooceánské hřbety, černí kuřáci (black smokers)

Origin of life

- **Where did life form**?
  - Probably *not at the Earth's surface* in shallow pools, as once believed
    - Presence of *oxygen would have inhibited* the "cooking" of "Stanley Miller soup"
  - Most likely in the **deep sea**, away from O_2, and probably near a "vent" of hot water
    - Modern *chemosynthetic bacteria* are abundant near vents on mid-ocean ridges
    - They derive energy by **consuming chemical compounds** and allowing reactions to occur within their cell membranes

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- Mid-ocean ridges are the **most likely** sites for origin of life and early bacterial evolution
  - **Enormous size** → many opportunities for key events to take place
  - **Anoxic** (no O_2) water with necessary amino acid building blocks present
  - **Other key materials** present
    - Phosphorus, nickel, zinc, clays
  - Modern "vent" bacteria are genetically the **most primitive archeobacteria known**

Certain cells ferment organic compounds to produce simple compounds and energy.
This is called **chemosynthesis**.

Chemosyntéza vs. fotosyntéza

Some of the early organisms became photosynthetic possibly due to a shortage of raw materials for energy. Photosynthesis was an adaptive advantage.

Produced their own raw materials. Autotrophs.

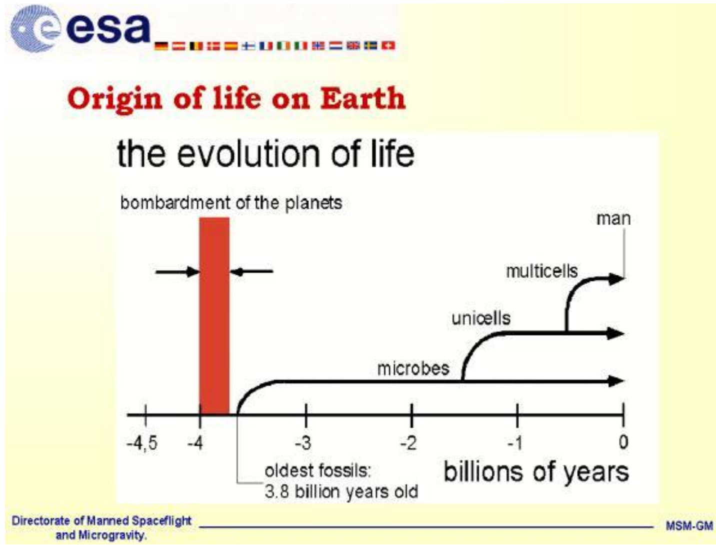
Examples = cyanobacteria (stromatolites)

Oxygen was a **WASTE PRODUCT.**

Život v archaiku

Archean Life

1. **Stromatolites** (cyanobacteria or BGA - blue-green algae) in carbonate sediment
   oldest are 3.4 - 3.5 by old
   also in rocks 2.8 - 3 by old more abundant in Proterozoic rocks
2. **Algal filament fossils** sometimes found
   3.5 b.y. at North Pole, western Australia
3. **Spheroidal bacterial structures** (Monera)
   Fig Tree Group, South Africa
   3.0 - 3.1 by
   prokaryotic cells; cell division?



Nejstarší fosílie

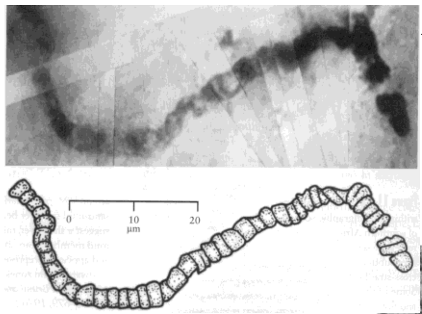
- *Archaeosphaeroides barbertonensis*

  skupina Onverwacht v Transvaalu (Jižní Afrika), silicity staré 3,4 Ga, kulovitá fosílie **prokaryotního typu**
- *Syphonophycus, Warrawoonella*

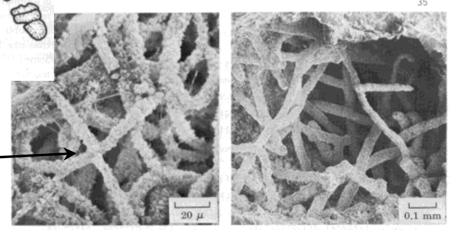
  skupiny Warrawoona v západní Austrálii,

  předjaderné organizmy ve zhruba stejně starých slabě metamorfovaných sedimentech

The Archean fossil record (cont.)



3.5 billion year old bacteria preserved in chert from Western Australia

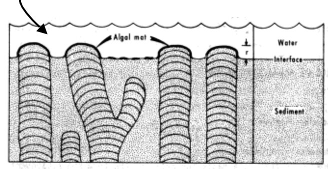


Modern cyanobacterial filaments

The Archean fossil record (cont.)

3.2 billion year old stromatolite from South Africa

Growth of cyanobacterial mats



stromatolity, horniny, které vznikají životní činností převážně **sinic a baktérií** na dně mělkých pánví a mají charakteristickou laminovanou stavbu. Dokládají rychlý rozvoj předjaderných mikroorganizmů rozhodně okolo 3,4 Ga let. Výskyt stromatolitů také dokazuje, že život začíná na Zemi utvářet další sféru - biosféru. Její aktivní zasahování do ostatních sfér a ovlivňování koloběhů látek se stává neodmyslitelnou součástí dalšího vývoje naší planety.

At right is a layered **stromatolite**, produced by the activity of ancient cyanobacteria. The layers were produced as **calcium carbonate** precipitated over the growing mat of bacterial filaments; photosynthesis in the bacteria depleted carbon dioxide in the surrounding water, initiating the precipitation. The minerals, along with grains of sediment precipitating from the water, were then trapped within the sticky layer of mucilage that surrounds the bacterial colonies, which then continued to grow upwards through the sediment to form a new layer. As this process occured over and over again, the layers of sediment were created. This process still occurs today; Shark Bay in western Australia is well known for the stromatolite "turfs" rising along its beaches.

SOUHRN

- Záhy po vzniku zemské kůry se vytváří redukční atmosféra a hydrosféra.
- Vznik první kontinentální kůry je spojen s procesy analogickými s procesy deskové tektoniky.
- Vytváří se pásma zelenokamenů a vznikají první sedimenty.
- Na konci archaika vzniká první velký superkontinent.
- V období mezi 3,8 a 3,4 Ga se na naší planetě objevují organické struktury řazené k prokaryotům.
- Na konci archaika dochází k velkému rozšíření prokaryot a hojné tvorbě stromatolitů.
- S produkcí kyslíku v oceánech je spojeno vypadávání dvojmocného železa z roztoků a tvorba páskovaných železných rud.